FACTORS OF CLIMATIC CONTROL.

(A Review.)

Dr. W. J. Humphreys[1] of the United States Weather Bureau has recently prepared a well-balanced and judicious summary of the factors which control climate so far as they are terrestrial in origin. He begins with the statement that small changes of climate occur at the present time, larger ones have apparently occurred in historic times, and still larger ones in the geologic past. These seem to differ in degree rather than nature and are due to a "complex control consisting certainly of all the factors that now are effective, and probably of no others." He then gives a table in which he sums up the known causes of climatic variations. These may be grouped according to the following classifications:

(1) The *"solar variation theory"* is dismissed with a wave of the hand—"seductively attractive—a seemingly complete *reductio ad absurdum.*" Such treatment may seem high-handed, but it is justifiable if, as Humphreys evidently assumes, the term "solar variation theory" means only the old idea that a diminution of the sun's heat would cause glaciation. One of his two brief criticisms is so cogent that it seems effectively to dispose of this old form of the solar hypothesis, although it has no bearing on the other and newer forms. "A change of the solar constant obviously alters all surface temperatures by a roughly constant percentage. Hence, a decrease of the heat from the sun would in general cause a decrease of the interzonal temperature gradients, and this in turn a less vigorous atmospheric circulation and a less copious rain or snowfall—exactly the reverse of the condition, namely, abundant precipitation, most favorable to extensive glaciation."

His other criticism of the solar hypothesis is that geologists agree that times of great climatic changes have usually also been times of great movement of the earth's crust, and hence "great solar changes and extensive mountain building must usually, if not always, have been coepochal—a seemingly complete reductio ad absurdum." In various forms Humphreys has several times repeated this statement in other publications. It is perfectly true that no one has yet published a detailed theory of how mountain building on the earth and climatic variations due to changes in solar activity can be causally connected. This, however, by no means proves that they are not thus connected. The reviewer believes that they are connected, and has nearly completed a manuscript in which this very question is discussed fully. It is not wise to be too positive in such matters, for many things which were deemed impossible a few decades ago are now matters of common knowledge, radioactivity, for example, and the transformation of one metal into another as of the radium products into lead. Moreover, in this whole discussion, it must be noted that Humphreys tacitly assumes that the action of the sun upon the earth is purely thermal, although there is a rapidly growing body of evidence that other agencies, such as electrical energy, or the selection of certain types of solar radiation by the atmospheres of the sun and earth may also play a part.

(2) The next topic in Humphreys' paper is *Croll's eccentricity theory.* As a main cause of glaciation, variations in the eccentricity of the earth's orbit, and hence in the distance of the earth from the sun at different seasons, were discarded three decades ago. They show a rigid periodicity and a frequency wholly out of harmony with the facts of the geological record. Moreover, they do not appear to be quantitatively sufficient. Nevertheless, such variations, together with the cyclical change in the season at which aphelion occurs, must have some slight effect on climate. Hence Croll's theory deserves a permanent though minor place in our discussion.

(3) The *carbon dioxide theory* rightly receives fuller discussion than either of those already mentioned. Abundant evidence is cited which suggests that a layer of carbon dioxide 40 centimeters thick would have practically as much blanketing effect as a layer indefinitely thicker. In other words, that amount of carbon dioxide, while having no effect on sunlight coming toward the earth, would filter out and thus retain in the atmosphere all the outgoing terrestrial heat that carbon dioxide is capable of absorbing. Adding more gas would be like adding another filter when the one in operation has already done all that that particular kind of filter is capable of doing. According to Humphreys' calculations a doubling of the carbon dioxide in the air would raise the average temperature only 1.3° C., and further additions would have practically no effect. Reducing the present supply by half would reduce the temperature by essentially the same amount. Hence this factor alone could scarcely have produced ice ages. Moreover, whatever climatic changes arise from variations in the carbon dioxide of the air must be extremely slow—far too slow to have any relation to short cycles such as those of historic times or even to glacial stages and epochs. Nevertheless they are not too slow to be a contributory factor in producing the longer swings of climate from one geological era to another. Hence we may set down carbon dioxide as a genuine though small factor in causing slow climatic changes, but probably of little importance in the greater and more rapid changes which have chiefly influenced organic evolution.

(4) *The volcanic hypothesis.*—The main body of Humphreys' article consists of a careful and convincing study of the effect of volcanic dust upon terrestrial temperature. He begins with a mathematical investigation of the size of dust particles, and their quantity after certain eruptions. Numerous equations demonstrate that the power of such particles to deflect light of short wave lengths coming from the sun is perhaps 30 times greater than their power to deflect and thereby retain the heat radiated in long waves from the earth. Hence, under circumstances like those which followed the Krakatoa eruption it is estimated that the dust veil might cause a reduction of about 6° C. in the earth's surface temperature, provided the veil continued year after year, as would happen if a Krakatoa were to belch forth dust every year or two. As in every such complicated problem, some of the author's assumptions are open to question, but this touches only their quantitative and not their qualitative value. It seems mathematically certain that if volcanic explosions were frequent enough and violent enough, the temperature of the earth's surface would be lowered.

Actual observation supports this theoretical conclusion. Humphreys gathers together and amplifies all that he and Abbot and Fowle[2] have previously said as to observations of the sun's thermal radiation by means of

[1] W. J. Humphreys: Factors of Climatic Control; Journal of the Franklin Institute, Philadelphia, December, 1919, and January, 1920.

[2] C. G. Abbot and F. E. Fowle: Volcanoes and Climate; Smithsonian Misc. Coll., vol. 60, 1913, 24 pp.
W. J. Humphreys: Volcanic Dust and Other Factors in the Production of Climatic Changes and their Possible Relation to Ice Ages; Bull. Mt. Weather Observatory, vol. 6, pt. 1, 1913, 26 pp.

the pyrheliometer. This summing up of the relation between the heat received from the sun and the occurrence of explosive volcanic eruptions leaves little room for doubt that at frequent intervals during the last century and a half a slight lowering of terrestrial temperature has actually occurred after great eruptions.

(5) *The form of the land.*—The last of the causes of climatic change discussed by Humphreys consists of a group of connected phenomena dependent upon movements of the earth's crust. As to the potency of such movements there is practical agreement among students of climatology and glaciation. That the height and extent of the continents, the location, size and orientation of mountain ranges, and the opening or closing of ocean gateways such as the Isthmus of Panama, and the consequent diversion of oceanic currents, exert a profound effect upon climate can scarcely be questioned. Such changes, however, are slow compared with the rapid pulsations to which climate has been subject during historic times and during the stages of glacial retreat and advance, or even in comparison with the epochs into which the Pleistocene, Permian and perhaps earlier glacial periods have been divided. Hence, while crustal movements are far more important than the eccentricity of the earth's orbit or the amount of carbon dioxide in the air, they do not explain glacial epochs and stages, historic pulsations, and present little cycles of climatic change. All these changes involve a relatively rapid swing from one extreme to another, while an upheaval of a continent, when once accomplished, can not be undone for a long time. Hence, such an upheaval if acting alone, would lead to a relatively permanent climate of a somewhat extreme type. Nevertheless, there is now little question that rapid climatic pulsations are closely associated with great movements of the earth's crust. Hence, some other agency is needed. It must show some logical connection with crustal movements, and yet must be able to vary rapidly and independently. Humphreys believes that volcanic eruptions supply this missing agency—the most important of all the factors involved in our problem. Hence, he comes to this final conclusion: 'Phenomena within the earth itself suffice to modify its own climate, and * * * there is much and accumulating evidence that these and these alone have actually caused great changes time and again in the geologic past."

Few thoughtful students will question that in the 72 pages of his article, which is a section of a book,* Humphreys has made a notable contribution to our knowledge of the climate of the past. He has rounded out the evidence as to the part played by volcanic dust in causing climatic changes, and has put this cause into proper relation with many other known causes. Nevertheless, along two important lines he seems not to have given enough emphasis to factors which are apparently of high importance. In the first place, there is a tacit assumption that, aside from the influence of movements of the earth's crust, the primary cause of all climatic changes must be variations in the amount of heat received, or, at least, retained by the earth. Nevertheless at least a part of the earth's climatic fluctuations apparently occur because alterations in the strength of the atmospheric circulation bring about a redistribution of temperature either directly as a result of stronger winds or indirectly as a result of alterations in cloudiness.[3] In the second place, Humphreys sees so clearly the importance of the purely terrestrial causes of climatic variations that he unconsciously slights the facts as to solar causes which he himself adduces at considerable length. Indeed in this matter he actually contradicts himself. Having said that there is accumulating evidence that "phenomena within the earth itself * * * and these alone have actually caused great changes * * * in the geologic past," he later states that "at least since 1750 * * * and presumably, therefore, since an indefinitely distant time in the past, the two phenomena, atmospheric temperature and sunspot numbers, have in general varied together."

The painstaking work of Köppen,[4] based on 20 million observations in all parts of the world during 100 years, shows the relation of terrestrial temperatures to the sun. Using all available records during the earlier decades and representative records in all parts of the world during later periods, Köppen showed beyond question that during the last century the earth was relatively warm during periods of sunspot minima and cool at times of maxima. The difference was greatest in equatorial latitudes, 0.6° C., and diminished in temperate latitudes, 0.4° C. For the earth as a whole it amounted to approximately one-twelfth of the difference which there appears to have been between the temperature at the height of the glacial period and now. At present either extreme lasts so short a time that it is of slight importance, but if the cooler conditions should persist decade after decade, they would constitute a distinct change of climate.

Köppen's work seems to contradict Humphreys' conclusion as to the paramount importance of terrestrial factors. Humphreys himself points this out without appearing to recognize its significance. On the basis of a much smaller number of stations than Köppen's, he has prepared a curve of terrestrial temperature which goes back to 1750. In its later portions it agrees essentially with Köppen's and shows clearly that the earth's temperature rises when sunspots are few and vice versa. In the earlier parts this is not so evident because the available records are few and imperfect. Nevertheless, even in the 18th century, the curves of sunspots and temperature show so much relationship that there seems good ground for believing that Humphreys is right in his conclusion as to the intimate relation between sunspots and atmospheric temperature "since an indefinitely distant time in the past," and wrong in thinking that phenomena within the earth itself are the only causes of climatic changes. From time to time, however, marked discrepancies appear between the curves of sunspots and of temperature. These in most instances occur immediately after violent volcanic eruptions. Humphreys, following Abbot and Fowle, makes allowance for such eruptions by superposing upon the sunspot curve another curve showing the intensity of the solar heat that reaches the earth's surface. A comparison of this curve with the temperature curve seems to show that at present at least four-fifths of the earth's variations in temperature, aside of course from those due to the seasons, are due to changes in the sun. Nevertheless, the other fifth, or less, seems to be due to volcanic dust or other purely terrestrial causes.

Other studies lead to a similar conclusion. Arctowski[5] in a very careful analysis of monthly temperatures brings

* The physics of the air, Franklin Institute, Philadelphia, 1920. pp. 556–629.

[3] A detailed discussion of this point has been prepared for separate publication.

[4] W. Köppen: Lufttemperaturen, Sonnenflecken und Vulcanausbrüche; Meteorol. Zeitschrift. vol. 31, 1914, pp. 303–328.

[5] H. Arctowski. The solar constant and variations of atmospheric temperature at Arequipa and some other stations. Bull. Amer. Geog. Soc., 1912, 44: 598–606.

out this point very clearly. By using the departure from the normal seasonal temperature at such stations as Arequipa in Peru, he demonstrates that when the effect of the seasons is eliminated, the earth normally passes through temperature cycles having a length of two or three years. These in turn are superposed upon larger cycles having the eleven-year sunspot period, and these in their turn on still larger cycles. Occasionally these cycles are interrupted by volcanic eruptions. But during the period from 1909 to 1913, which includes the great eruption of Katmai in Alaska, the decrease in temperature due to this cause was less than the difference between the maxima and minima of the cycles in the sunspots. The similarity of Arctowski's curves in different parts of the world seems to demonstrate that the cycles must be due to some outside cause which can scarcely be anything except the sun. Thus both from Köppen's figures and those of Humphreys, Abbot, and Fowle, and from Arctowski's independent and more detailed studies, it appears that at the present time far the greatest control of the earth's temperature is variations in the sun. If a similar relation prevailed in the past, solar variations must have taken their part with terrestrial phenomena among the main causes of geological changes of climate.[6]—*Ellsworth Huntington.*

[6] Geological evidence, however, points to periods of much greater volcanic action than in recent times; while we have no evidence of the occurrence of appreciably greater solar variability. Therefore the terrestrial factors may have been relatively much more important in controlling climatic changes in the geologic past than now.—*Editor.*

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C. FITZHUGH TALMAN, Professor in Charge of Library.

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